International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 7, Issue 2, Apr 2017, 47-56

A CASE STUDY ON RESPONSE OF ALLOY GEAR STEELS TO CASE CARBURIZING AND IT'S EFFECT ON WEIGHT OPTIMIZATION OF A TRANSMISSION SYSTEM

PRASAD SAKAT[1], ADWAIT VERULKAR[2], DARSHAN BAMB[3] & SANTOSH JOSHI[4]

[1, 2, 3]Research Scholar, Department of Mechanical Engineering, Vishwakarma Institute of Technology, Pune, India

[4]Assistant Professor, Department of Mechanical Engineering, Vishwakarma Institute of Technology, Pune, India

ABSTRACT

The strength of a material is a very crucial design parameter from an engineer's standpoint for designing a mechanical system with a primary design objective of optimization or minimization of system weight. This is particularly true for designing a transmission system for an automobile as a reduction in weight of the vehicle has a direct and significant impact on fuel consumption and the overall dynamic performance in terms of acceleration and maneuverability. Selection of a gear material is done primarily on the basis of strength. The gears are further heat treated after manufacturing to improve surface hardness and consequently the pitting strength. However, the effect of surface heat treatment on the strength of the material is not considered. Because of this, the system is prone to be significantly overdesigned. In this paper, a case has been presented, in which the augmentation in material strength due to case carburizing has been discussed, and based on the results, a suitable material was selected. Furthermore, the resulting savings in design weight has been discussed in detail. By following this approach 50.37% reduction in system design weight was achieved. This optimization was achieved because of improvement in material yield strength by 107.23% and 108.08% in ultimate tensile strength.

KEYWORDS: Optimization, Automobile, Transmission, Heat Treatment, Pitting, Yield Strength & Ultimate Strength

Received: Jan 11, 2017; **Accepted:** Feb 19, 2017; **Published:** Feb 23, 2017; **Paper Id.:** IJMPERDAPR20175

Case Study

INTRODUCTION

In the earlier days, the longevity of any mechanical system was achieved by maintaining a high factor of safety with not much focus on optimization. This philosophy of design introduced a significant amount of overdesign. However recent times demand a design should not only satisfy the functional requirement but also it should do it in an optimized fashion. Optimization may be in terms of minimization of cost, minimization of weight or maximizing certain parameter. Irrespective of the objective of the optimization study, the strength of the material used in the design of the concerned mechanical system has a direct and significant impact.

DESCRIPTION OF CASE STUDY

The paper presented henceforth discusses a case study of an automobile transmission system. Optimization in this field has been a subject of significant research. Several approaches to reduce the transmission weight have been tried. Some discussions have been done on a selection of appropriate cross section of the gearbox casing [IX]. Also, some research has been done to reduce the weight of transmission system by using composite materials [X]. However making this approach commercially viable is a difficult task. Other studies show that replacing steel with aluminum alloys could be a viable option [XI]. This approach although seems

feasible in terms of cost when compared to the composite approach, aluminum has major drawbacks in terms of wear strength and high-temperature strength for high-speed engine applications.

The basic element of any conventional transmission system is a gear. The two main criteria for selection of material for gear are the ultimate tensile strength of the material and the surface endurance strength or wear strength of the material. In the majority of the cases, a material of high ultimate strength and relatively low wear strength is chosen for gears. Due to this, the size of the transmission system is reduced. Any transmission system almost always runs in a lubricant and hence the wear of the teeth is not significant. Moreover, the gears are hardened to a sufficient case depth and a sufficient hardness value which improves its surface endurance strength while maintaining toughness at the core. There are several ways in which this can be achieved viz. case carburizing, nitriding, flame hardening etc. This procedure, however, has a severe drawback. Any heat treatment process done with the objective of improving the surface endurance strength has an effect on the strength of the material as well. This effect is usually neglected as the design of gears from a strength point of view is based on the ultimate tensile strength of the material before the hardening process. Since the ultimate strength of material increases after hardening, the components are overdesigned. The response of 4 high strength alloy gear steels to case carburizing is present in the following manuscript. Henceforth the effect of this response on the design in terms of weight savings is presented as a case study.

Figure 1 shows a block diagram illustrating the power flow in the transmission. The engine used in the vehicle is Briggs and Stratton 20S232-0036-F1 305 cm^3 OHV Intek Single Cylinder Gasoline Engine. The peak torque occurs at 2800 RPM of 19.66 N-m (14.50 lb.-ft.) and it gives peak power of 7.46 kW at 3600 RPM.

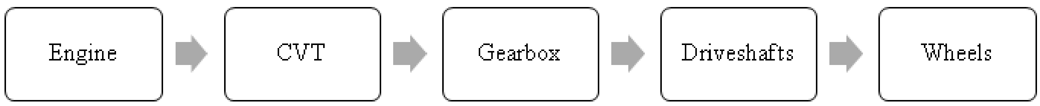

Figure 1: Layout of ATV Powertrain

Variation of the overall transmission ratio i.e. a high reduction at low speeds for better acceleration characteristics and a taller gear ratio at high cruising speeds for better fuel economy is achieved through a Gaged Model GX9 Continuously Variable Transmission (CVT) System. A 2 step single speed compound gear train serves only the purpose of torque magnification and not of speed variation and thus it has a pre-determined speed reduction of 8.0278. This gear train is the subject of the case study. After the single speed gearbox, the power is transmitted to the wheels through a driveshaft and sliding type of constant velocity joints.

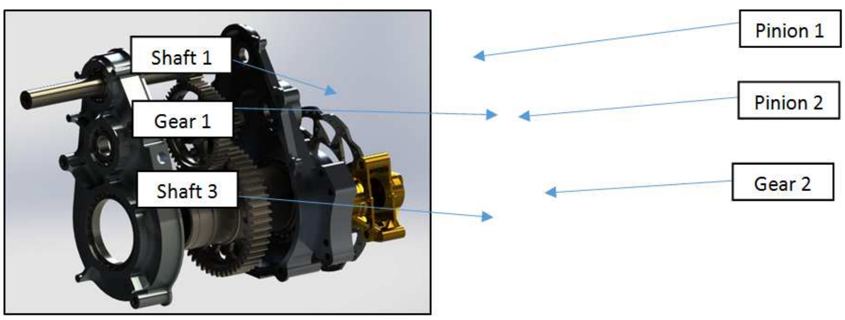

Figure 2: Exploded View of Gearbox (Modelled in Solidworks 2015)

Figure 2 shows exploded view of the gearbox. As it is a 2 step single speed gear train, it consists of 3 shafts and 4 gears, material for which is kept same. The first shaft (shaft 1) receives power from the Secondary CVT Pulley. The first pinion (Pinion 1) is integrated with shaft 1 which in turn transmits power to Gear 1 mounted on the second shaft (Shaft 2). A second pinion (Pinion 2) is mounted on shaft 2 beside gear 2 in compound arrangement. Pinion 2 finally meshes with a second gear (Gear 2) which is integrated with a third hollow shaft (Shaft 3). Shaft 3 has provisions for supporting the drive shafts and the profile cut within acts as half part of the constant velocity joints. All the shafts are supported on SKF deep groove ball bearings.

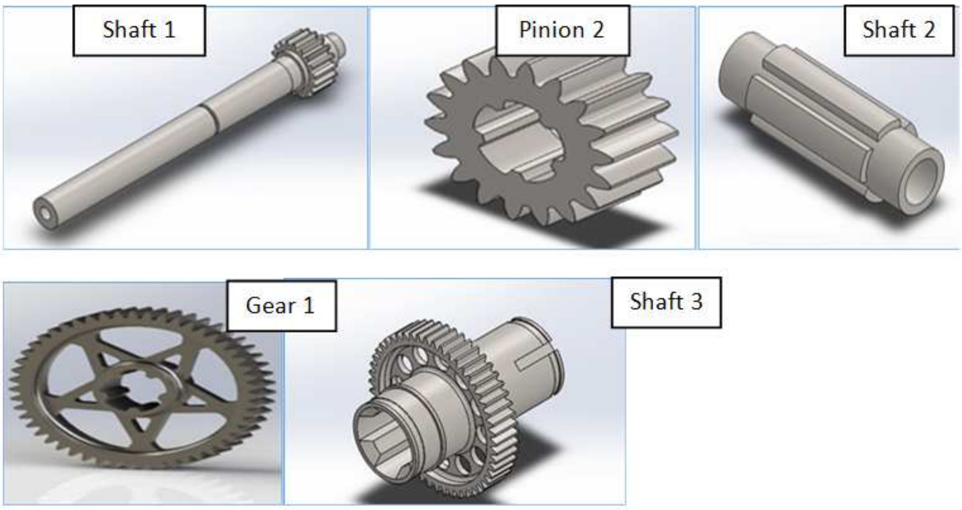

Figure 3: CAD Models of Gearbox Components

The specification of the required transmission system is given in Table 1.

Table 1: Gear Train Specifications

Speed Reduction Ratio	**Stage I**	**2.83**	
	Stage II	**2.83**	
	Overall	**8.0278**	
Teeth Distribution		Pinion	Gear
	Stage I	18	51
	Stage II	18	51
Type of gearing	Spur Gear		

As the application demands high performance, minimizing the weight and rotational inertia of the transmission system is a primary target in design. As the strength of the material used has a significant impact on the weight of the system, four high strength alloy steelshave been shortlisted. Description of these steels is given in Table 2.

Table 2: Chemical Composition of Alloy Gear Steels under Consideration

Sr. No.	**Material Name**	**Carbon Content (wt/wt %)**	**Alloy Content (wt/wt %)**			
			Ni	**Cr**	**Mo**	**Mn**
1.	20MnCr5	0.17-0.22%	-	1.0-1.3%	-	1.1-1.4%
2.	SAE 8620	0.18-0.23%	0.4-0.7%	0.4-0.6%	0.15-0.25%	0.7-0.9%
3.	SAE 9310	0.08-0.13%	3-3.5%	1-1.4%	0.08-0.15%	0.45-0.65%
4.	EN 36	0.12-0.18%	3.00-3.75%	0.6-1.1%	-	0.3-0.6%

Selection of final material was based on material testing results. The procedure used for material testing has been described in the subsequent section.

HARDENING PROCEDURE

Hardening of all the specimens was done at Darekar Heat Treatment Pvt. Ltd. Bhosari Pune. The specimens were gas carburized in pit type furnace to a case depth of 1.2 mm and hardness of 60 HR_c. The process parameters of hardening are discussed in Table 3.

Table 3: Properties of Hardening Process

Loading Temperature	850^{o} C
Carburizing Temperature	920^{o} C
Activation Time	2 hours 30 minutes
Activation Carbon Potential	1140 mV (i.e. 0.9% – 1% CP)
Diffusion Temperature	920^{0} C
Diffusion Time	60 min
Diffusion Carbon Potential	1115 mV (i.e. 0.7%-0.8%CP)
Hardening Temperature	840^{0} C (920 – 840: Furnace heat drop)
Hardening Carbon Potential	1090-1100 mV (i.e. 0.5%-0.6% CP)
Oil Used For Quenching	Poweroil 32X (Medium quench oil)
Oil Temp Before Quenching	$50\text{-}70^{o}$ C
Oil Temp After Quenching	90^{o} C
Holding Time in Oil	40-50 min hold
Tempering at	$160^{o}\text{-}170^{o}$ C for 2 hours

The above processes are mentioned in the sequence they are carried out. After that, the specimens were cooled up to room temperature.

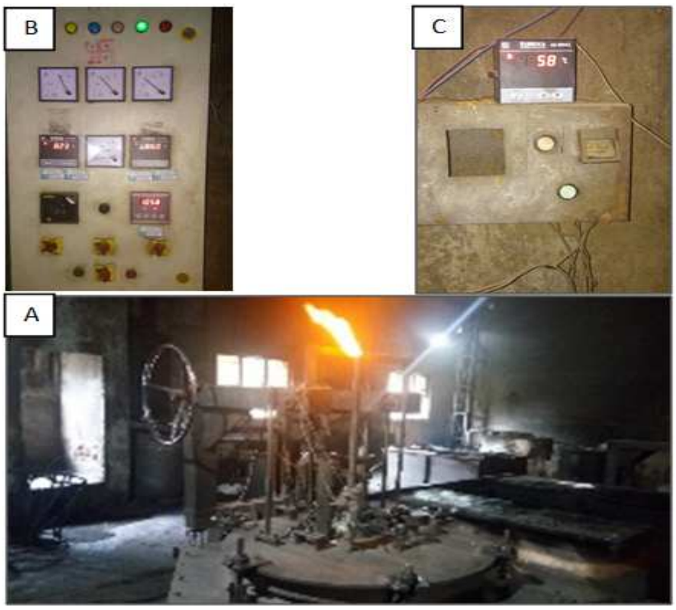

Figure 4: A) Pit Furnace and Oil Bath B) Control Panel C) Oil Bath Temperature

TESTING SETUP

Two specimens of each material were prepared as per standards ASTM E8: 2013 [I] (for SAE 8620 and SAE 9310) and ISO 6892-1: 2009 [II] (for 20MnCr5 and EN36). One sample of each material was tested on Universal Testing Machine (Make: FIE, Model: UTN60) without hardening while the other sample of each material was tested after case carburizing with a case depth of 1.2 mm and hardness of 60 HRc.All the specimens were tested at Elca Quality Systems and Calibrations Pvt. Ltd. Bhosari, Pune. 20MnCr5 test specimen without hardening is shown in Figure 4.

Figure 5: 20MnCr5 Test Specimen without Hardening

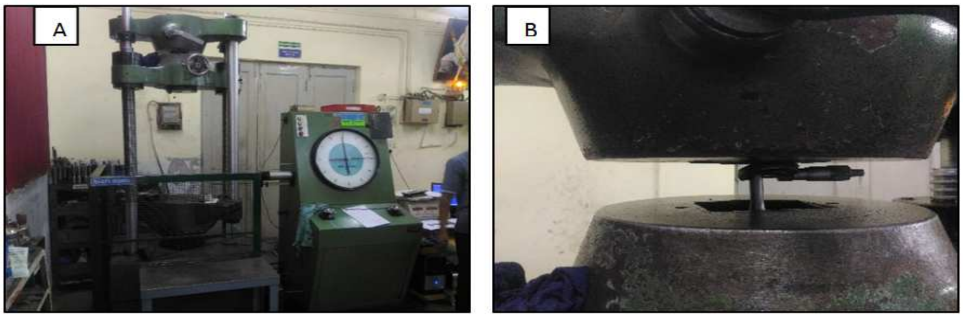

Figure 6: A) FIE UTN 60 UTM. B) Test Specimen held in UTM

TESTING RESULTS AND DISCUSSIONS

The specimens were tested and the Yield Strength, Ultimate Tensile Strength and Percentage Elongation of each specimen before and after hardening have been presented in the form of histograms.

Figure 7: Fractured Test Specimen

Effect on Yield Strength

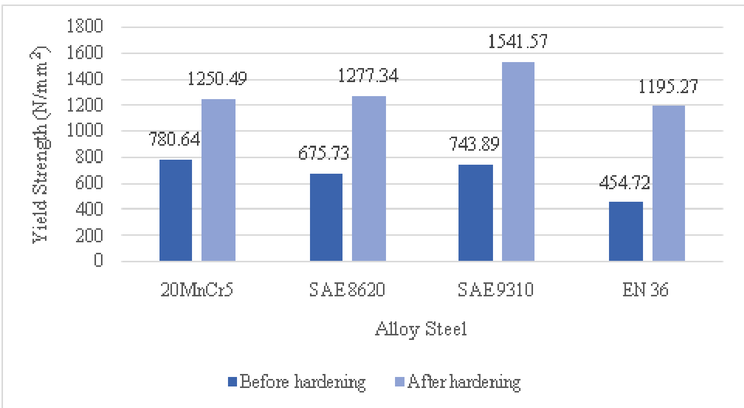

Figure 8: Effect on Yield Strength

As it is clear from the test results, SAE 9310 showed a significant improvement in yielding characteristics after hardening. The yield strength of SAE 9310 increased by 107.23%.

Effect on Ultimate Tensile Strength

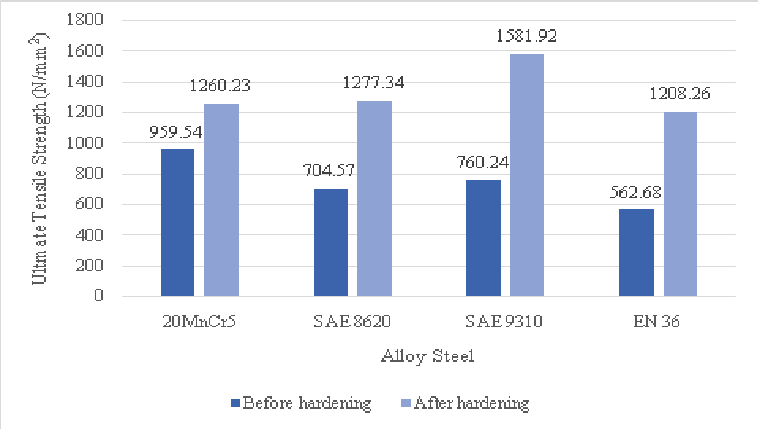

Figure 9: Effect on Ultimate Tensile Strength

Similar to the results of yield stress, the ultimate strength of SAE 9310 was found to be maximum, and the material showed a great response to hardening in terms of increase in ultimate tensile strength. The percentage increase in ultimate strength was 108.08%.

Effect on Percentage Elongation

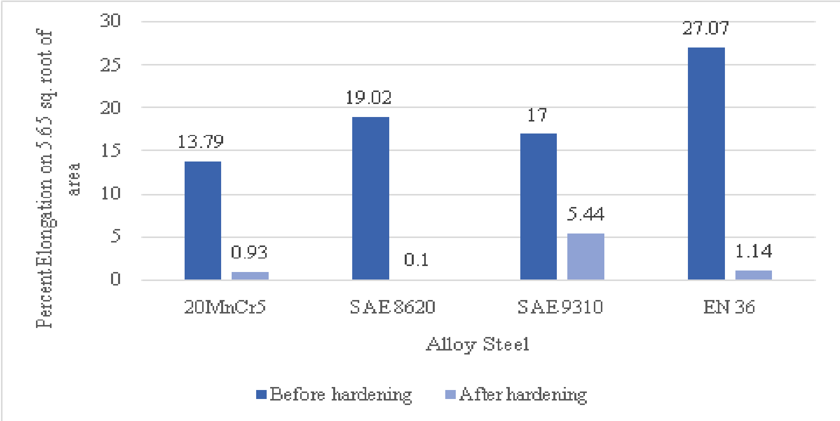

Figure 10: Effect on Percentage Elongation

The material was to be selected for gearing, thus, it should not only have a high strength, but also an appreciable toughness. The deterioration in toughness of SAE 9310 was found to be comparatively less. The percentage elongation of SAE 9310 decreased by 68%.

From the above results, SAE 9310 was selected as the gear as well as shaft material.

TOTAL DESIGN WEIGHT SAVINGS

The gears have been designed based on AGMA standard [V] and Buckingham's Equation [III]. The design was verified in KISSSoft 2013 (gear train analysis software). The design of shaft was based on ASME code [III]. Also, various other considerations such as fatigue [VI] and allowable deformation for the proper functioning of bearings have been

taken. The entire system has been designed for both the strengths before and after hardening to do a comparison study. After the analytical design was completed on excel, all the components were modeled in Solid works 2015 (CAD software) and thus the design weight of the individual components was estimated. The results of the comparison study have been summarized in Table 9 below.

Table 4: Weight Savings in Each Component Due to Increase in Strength after Hardening

Component	Weight before Hardening (gms)	Weight after Hardening (gms)	Weight Savings in (gms)	Percent Weight Saving
Shaft 1	658	391	267	40.58
Shaft 2	239	149	90	37.66
Shaft 3	763	442	321	42.07
Pinion 1	278	135	143	51.44
Gear 1	2012	982	1030	51.19
Pinion 2	803	382	421	52.43
Gear 2	5823	2768	3055	52.46
Total	**10576**	**5249**	**5327**	**50.37**

CONCLUSIONS

In the work undertaken, the improvement in material failure characteristics as a result of case carburizing was studied. For this study, four commonly used alloy gear steels viz. SAE 8620, SAE 9310, 20MnCr5 and EN 36 were chosen. Two tensile test specimens as per ASTM and ISO standards of each material were prepared. Out of these, one specimen of each material was case carburized to the application specifications of 60 HRc and 1.2 mm case depth, whereas the other specimen was kept unaltered. All the specimens were tested on a UTM and the results of these tests have been reported in terms of percentage increase in material yield strength, ultimate tensile strength and percentage elongation. From the results, it is observed that SAE 9310 showed the best results with 107.23% increase in yield strength and 108.08% increase in ultimate tensile strength without sacrificing the ductility significantly. Thus it can be concluded that increase the surface endurance strength of a material due to case carburizing is also accompanied by a corresponding increase in yield and ultimate tensile strength.

Furthermore, a comparison study for a transmission system was presented. In this study, the potential for weight savings due to consideration of improved strength due to case carburizing was presented. The design procedure was based on ASME code for shaft design and Buckingham's equation for tooth failure. A comparison between estimated weight of components by considering strength prior to hardening and after hardening, keeping the design procedure same, was performed. By following this approach a weight saving potential of 50.37% was observed. It is thus concluded that hardening significantly affects the strength of the material and the incorporation of its effect in design is essential for design optimization.

ACKNOWLEDGEMENTS

We would like to thank Mechanical Engineering Department, Vishwakarma Institute of Technology, Pune for providing us valuable support for completion of this work. We would also like to thank the Workshop Department for providing us with the tools required for assembly and manufacturing of the parts. Last but not the least, we acknowledge the continuous support of Team Endurance Racing.

REFERENCES

1. *ASTM E8 / E8M – 13- Standard Test Methods for Tension Testing of Metallic Materials.*
2. *ISO 6892-1:2016- Metallic materials -- Tensile testing -- Part 1: Method of test at room temperature.*
3. *Bhandari V. B., (2015).Design of Machine Elements, McGraw Hill Education (India) Private Limited, pp. 330-389, 646-693.*
4. *Lemanski, A., "Gear Design," SAE Technical Paper 680381, 1968, doi: 10.4271/680381.*
5. *AGMA 901-A92, A Rational Procedure of Preliminary Design of Minimum Volume Gears.*
6. *Gujar R. A., Bhaskar S. V., (2013).Shaft Design under Fatigue Loading By Using Modified Goodman Method, International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622, Vol. 3, 1061-1066.*
7. *Navle M. S., Dr. Damale A. V., (2016).Weight Optimization of the Gear Train – A Review, International Advanced Research Journal in Science, Engineering and Technology, Vol. 3, Special Issue 1, 30-32.*
8. *BožidarRosić, Multicriterion Optimization of Multistage Gear Train Transmission, Mechanical Engineering Vol.1, No, 8, 2001, pp. 1107 – 1115.*
9. *Shrikant S. Joshi, Jaykarthikeyan P. V., (2014). Transmission Weight & Efficiency Optimization in Off Road Vehicle (Tractor Gearbox), Control Theory and Informatics, Vol.4, No.1, 58-67*
10. *HarshalBankar, VirajShinde, P. Baskar, (2013).Material Optimization and Weight Reduction of Drive Shaft Using Composite Material, IOSR Journal of Mechanical and Civil Engineering, Volume 10, Issue 1, 39-46*
11. *C.Veeranjaneyulu, U. HariBabi, (2012). Design And Structural Analysis Of Differential Gear Box At Different Loads, International Journal of Advanced Engineering Research and Studies, Vol. I Issue II, January-March, 65-69.*